Arizona Geological Survey

ARIZONA GEOLOGY

(formerly *Fieldnotes*)

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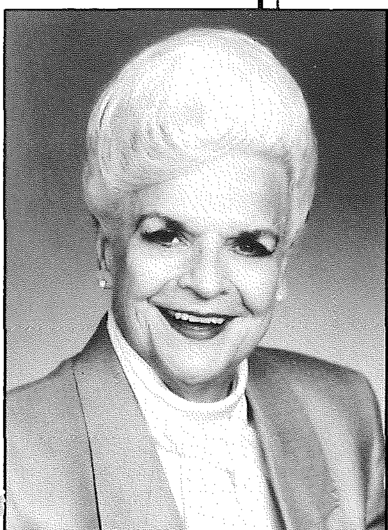
Office of the Governor

PROCLAMATION



AZGS CENTENNIAL

On December 14, 1989, Governor Rose Mofford issued this proclamation commemorating the century of service that the Arizona Geological Survey and its predecessors have provided to citizens of the State of Arizona.

* CENTENNIAL CELEBRATION OF GEOLOGICAL SURVEY IN ARIZONA *

WHEREAS, the State of Arizona has been richly endowed with metallic and nonmetallic mineral resources, and the discovery and exploitation of these resources was, and continues to be, a major factor in the development and economy of the State and the Nation; and

WHEREAS, the State of Arizona has experienced substantial population increase since the 1950's and is projected to attract new residents at a rapid rate for many years; and

WHEREAS, wise management of the State's lands and mineral resources requires objective, scientific geologic data and assistance, which will become increasingly important as population growth causes the competition for and conflict over land and mineral resources to accelerate;

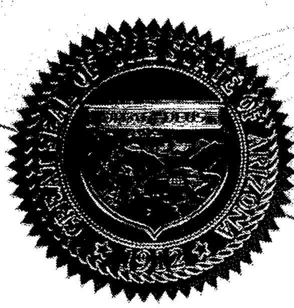
WHEREAS, the Arizona Geological Survey, an agency of the State of Arizona, and its predecessors, the Arizona Bureau of Geology and Mineral Technology (1977-1988), the Arizona Bureau of Mines (1915-1977), the University of Arizona "Bureau of Mines" (1891-1915), and the Office of the Territorial Geologist (1889-1912), have investigated Arizona's geological framework and mineral resources and have served as a major source of information and assistance since March of 1889;

NOW, THEREFORE, I, Rose Mofford, Governor of the State of Arizona, do hereby proclaim March, 1989 through March, 1990, as a

* CENTENNIAL CELEBRATION OF GEOLOGICAL SURVEY IN ARIZONA *

and I commend and congratulate the Arizona Geological Survey and its predecessors for one hundred years of outstanding contributions and service, and I challenge them to continue to investigate Arizona's geologic framework, mineral and energy resources, and geologic hazards and limitations in order to provide the level of information and service that will be required in the years to come.

IN WITNESS WHEREOF I have hereunto set my hand and caused to be affixed the Great Seal of the State of Arizona



Rose Mofford
GOVERNOR

DONE at the Capitol in Phoenix on this the fourteenth day of December in the Year of Our Lord One Thousand Nine Hundred and Eighty-nine and of the Independence of the United States of America the Two Hundred and Thirteenth.

ATTEST: Jim Shumway
Secretary of State

Kartchner Caverns State Park: A Geologic Showpiece

by Charles G. Graf
c/o Arizona Conservation Projects, Inc.
245 S. Plumer, Suite 16
Tucson, AZ 85719

Bats spiral out of the dusty limestone sinkhole soon after the rays of the setting August sun leave the eastern slope of the Whetstone Mountains in southeastern Arizona. The subterranean splendor from which these bats emerge, now known as Kartchner Caverns, had awed Tucson cavers Gary Tenen and Randy Tufts since they discovered the cave in 1974. Their find was so exceptional–and vulnerable–that it remained a secret for the next 14 years. Not until Governor Rose Mofford signed a bill on April 27, 1988, making Kartchner Caverns a State park, was the veil of secrecy lifted.

Now under the stewardship of Arizona State Parks and newly appointed park manager, Jeff Dexter, Kartchner Caverns is being managed in anticipation of a public opening in 3 to 4 years. Arizona State Parks intends to open the cave for visitation and education, while continuing to preserve it in as pristine a state as possible. Because Tenen and Tufts took great care while exploring the cave, its condition is nearly undisturbed. For example, they marked all routes of travel to keep traffic to one path, with the result that 95 percent of the cave floor remains untrodden. As a first step in opening Kartchner Caverns in an environmentally sensitive manner, Arizona State Parks has contracted for an extensive predevelopment study of the meteorological, geological, hydrological, and biological aspects of the cave. This study, which will be completed in 1991, is being conducted by Arizona Conservation Projects, Inc., a nonprofit organization founded to pursue conservation and education activities related to the cave.

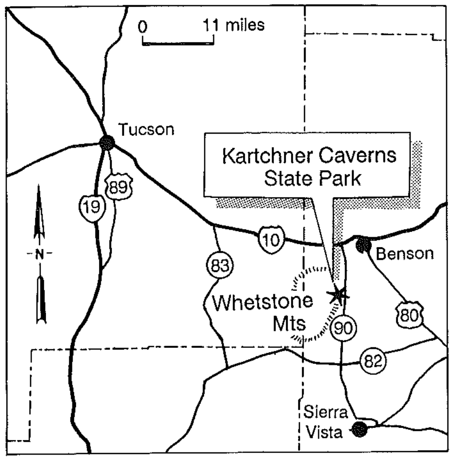


Figure 1. Location map of Kartchner Caverns State Park.

Establishing the State Park

Most publicly known caves in Arizona have been defaced, stripped of formations, and littered with trash. Hoping to avert this fate for the caverns, in 1978 Tenen and Tufts approached the owner of the land, James Kartchner of St. David, with an offer to buy the parcel containing the cave. Kartchner was not aware of the cave on his property. When their offer to buy was rejected, Tenen and Tufts divulged their secret and, with the Kartchner family, initiated a long and careful process of exploring, studying, and mapping the cave.

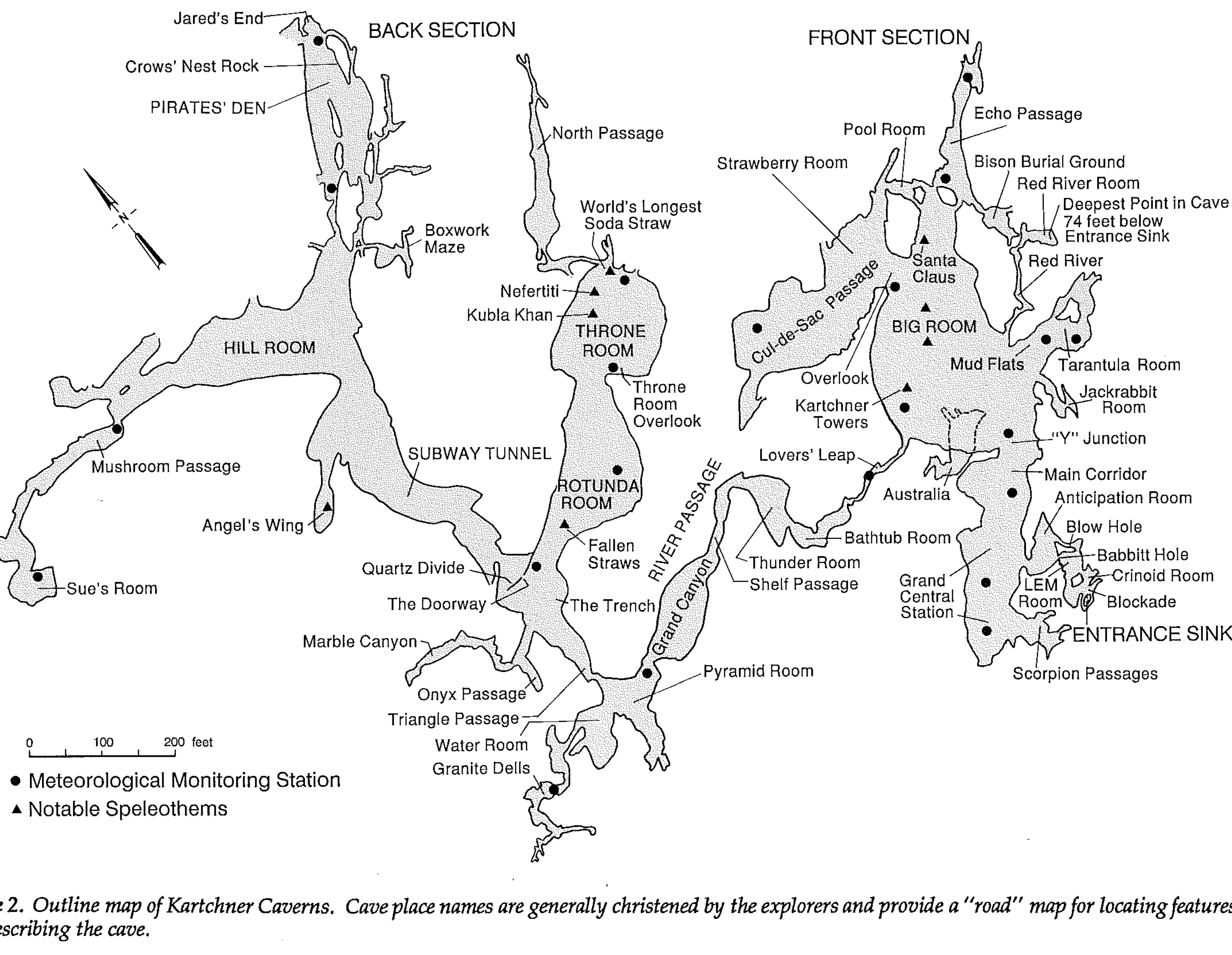


Figure 2. Outline map of Kartchner Caverns. Cave place names are generally christened by the explorers and provide a "road" map for locating features and describing the cave.

Eventually, Tenen, Tufts, and the Kartchners concluded that the cave would be best protected by a land-management agency. An initial contact with Arizona State Parks elicited interest, but the agency did not have the resources to buy the land. Undeterred, the group arranged a trip into the cave for then-governor Bruce Babbitt, requiring an oath of secrecy from him as they had from all others involved in the project. After his visit, Babbitt directed them to The Nature Conservancy, which offered to assist Arizona State Parks in acquiring the site.

This expanded group worked in secret for 2 years with key legislators to make Kartchner Caverns a State park. To do this, they had to devise a permanent funding mechanism for State parkland purchases. When a plan acceptable to legislative leaders was completed and Governor Mofford, informed of the group's strategy, was prepared to sign the bill, the key legislators added a floor amendment making Kartchner Caverns the first State park to be purchased with the new fund. To the surprise of the rest of the Legislature, the news media, and the public, this superlative jewel was revealed, and at the same time, given protection as a State park.

Cave Location and Dimensions

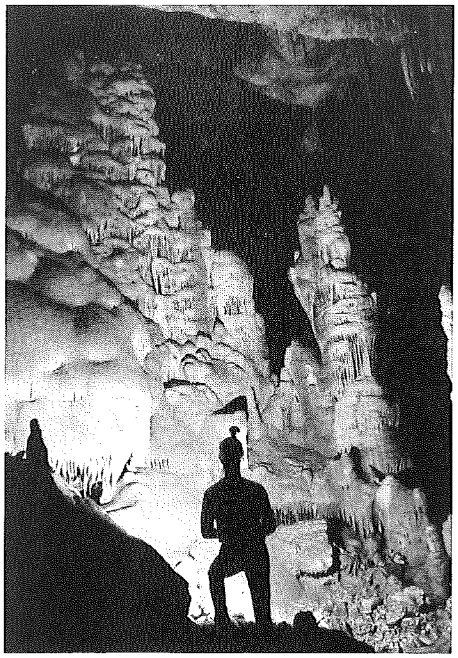
Kartchner Caverns is located beneath a low hill of limestones at the base of the eastern flank of the Whetstone Mountains, 10 miles southwest of Benson and 21 miles northwest of Sierra Vista (Figure 1). The State park embraces 550 acres of limestone hills and adjacent alluvial slopes that are between 4,520 and 6,078 feet in elevation. The only significant prior use of the land was for cattle grazing.

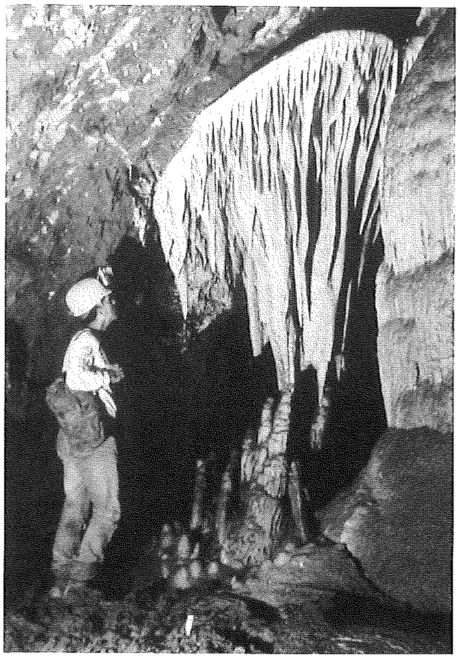
The Whetstone Mountains steepen abruptly to the west of the park boundary, cresting 3 miles away at an elevation of 7,388 feet. To the east, an alluvial slope descends gradually for 8 miles to the San Pedro River. Picturesque Guindani Canyon, an ephemeral drainage incised deeply into the Whetstone Mountains toward the west, is the only major drainage that crosses the park.

The mapped length of all of the segments of Kartchner Caverns totals 12,648 feet (2.4 miles) and the known vertical extent is 119 feet. Surprisingly, the entire cave lies within a rectangular area of 1,600 feet by 1,100 feet. Of the three major chambers of the cave, the Big Room is the largest, about 350 feet long and 180 feet wide (Figure 2).

Unique Speleothems

Kartchner Caverns is replete with a dazzling array of speleothems (secondary cave mineral deposits). It contains 18 major types and many subtypes (Carol Hill, personal commun.). Excellent examples abound





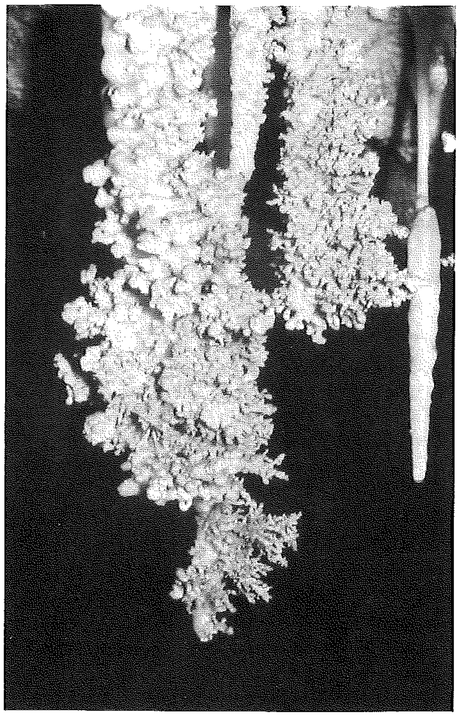


Figure 3 (top left). A cave explorer is silhouetted against some of the speleothems that cover nearly one acre of floor area in the Big Room. Photo by Bob Buecher and Steve Holland; © 1988 Arizona Conservation Projects, Inc.

Figure 4 (top right). Cave codiscoverer Randy Tufts examines the Angel's Wing, a rather uncommon speleothem known as a shield that is abundant in Kartchner Caverns. Photo by Bob Buecher and Steve Holland; © 1988 Arizona Conservation Projects, Inc.

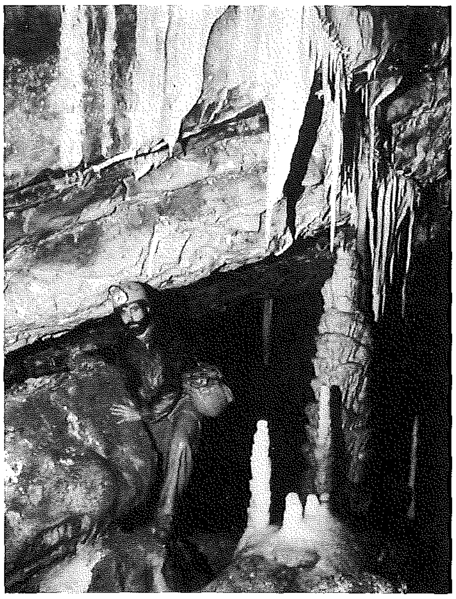
Figure 5 (bottom right). Different varieties of corallike speleothems are common in the cave. Those shown in this photo, located in the Big Room near the Echo Passage, are composed of aragonite and grew on the ends of stalactites. Photo by Bob Buecher and Steve Holland; © 1988 Arizona Conservation Projects, Inc.

of stalactites, stalagmites, columns, helictites, shields, soda straws, flowstone, and draperies (Figures 3, 4, and 5; see Hill and Forti, 1986, for speleothem descriptions and growth mechanisms.) A special distinction for Kartchner Caverns is that it houses the longest (21.16-foot) known soda-straw stalactite in the world (Figure 6). As the name implies, these speleothems are vertically hanging tubular stalactites that resemble soda straws. This length exceeds the previous record of 20.47 feet for a soda straw from a western Australian cave (Hill and Forti, 1986). Kartchner Caverns also contains the tallest and probably most massive column in Arizona: the 52-foot Kubla Khan.

Nearly all of the speleothems in Kartchner Caverns are composed of calcite. Aragonite, a polymorphic form of calcite, is also present, but comprises less than 1 percent of the total secondary mineral deposits (Carol Hill, personal commun.). No sulfate minerals have yet been found; the presence of nitrocalcite, a rare cave mineral, has been verified, however (Carol Hill, personal commun.). Many of the speleothems are colored in pastel shades of brown, yellow, orange, red, and pink. X-ray diffraction analyses of samples collected from some of these speleothems indicate that the color is due to amorphous or organic material, rather than crystalline minerals (Carol Hill, personal commun.).

Geologic Setting and History

The limestones of the hill overlying Kartchner Caverns dip westward to southwestward at angles varying between 10° and 40°. Kartchner Caverns cuts impres-



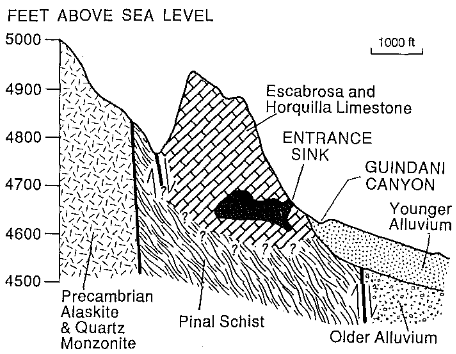


Figure 6 (top left). Cave codiscoverer Gary Tenen edges by speleothems near the top of the Throne Room, which contains the longest soda-straw stalactite known in the world. Photo by Bob Buecher and Steve Holland; © 1988 Arizona Conservation Projects, Inc.

Figure 7 (bottom left). Geologic cross section showing location of Kartchner Caverns in Escabrosa Limestone. Vertical exaggeration is 9X.

sively across these dipping beds, reflecting a solutional origin under shallow phreatic (water-table) conditions (Figure 7). Regional geologic maps (Creasey, 1967; Wrucke and Armstrong, 1984) show that the rocks at Kartchner Caverns mainly consist of Escabrosa Limestone, which is approximately 337 million years (m.y.) old (Mississippian age), with a much smaller exposed area of Horquilla Limestone, which is approximately 324 m.y. old (Pennsylvanian age). Based on the maps, the entrance to Kartchner Caverns appears to be within Horquilla Limestone; however, as indicated by ongoing geologic mapping at a scale of 1:600 (1 inch = 50 feet), the limestone hill is more disrupted and the geology more complex than the previous, less detailed maps show. For example, conodonts (fossilized body parts of microscopic marine animals) obtained from the limestone at the entrance sinkhole identify the outcrop as Escabrosa rather than Horquilla Limestone (Dr. Kenneth Thomson, Southwest Missouri State Univ., personal commun.). In fact, most, if not all, of the cave appears to have formed within the Escabrosa Limestone (Dr. Kenneth Thomson, personal commun.).

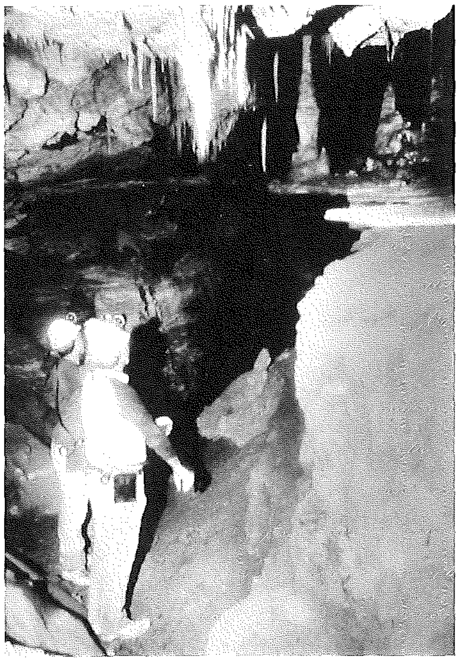
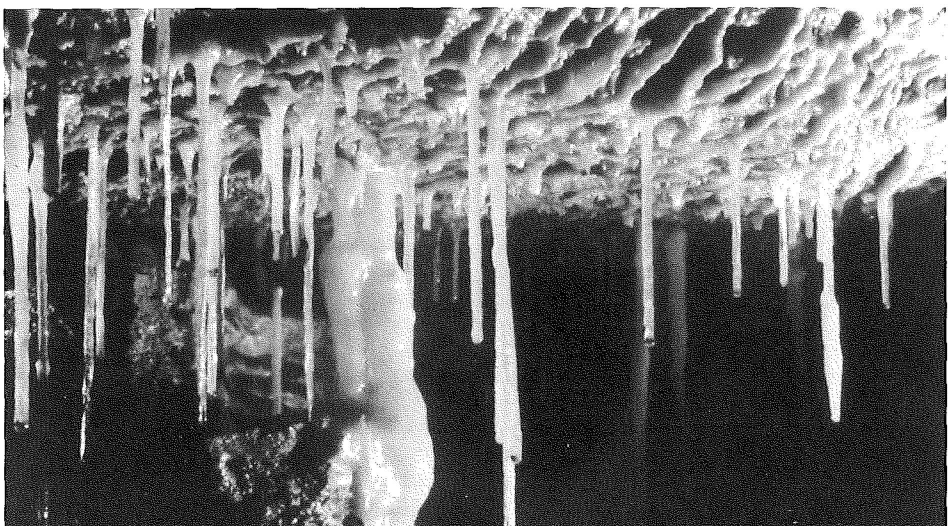


Figure 8 (above). Clastic sediments, such as this flowstone-capped sequence in the Grand Central Station, provide evidence of the speleogenetic history of Kartchner Caverns. After the sediments were deposited by an in-cave stream, calcium carbonate precipitated from flowing water on the cave floor, thus creating the flowstone. Subsequent stream activity eroded the sediments, carved the channel, and undercut the flowstone. Photo by Bob Buecher and Steve Holland; © 1988 Arizona Conservation Projects, Inc.

Figure 9 (below). These soda straws in the Shelf Passage, like many other speleothems in the cave, continue to grow as calcite slowly precipitates from dripping water. Photo by Bob Buecher and Steve Holland; © 1988 Arizona Conservation Projects, Inc.

The three main chambers of the cave (Big Room, Rotunda Room-Throne Room, and Subway Tunnel - Pirates' Den) are aligned along northeast-trending faults. The faults themselves do not appear to have acted as permeable zones that controlled limestone dissolution; rather, ground water appears to have flowed more readily along fractures or joints within the crest of narrow anticlinal folds adjoining the fault surfaces. These shallow folds appear to be drag features produced during faulting.

Kartchner Caverns probably began forming several hundred thousand years ago and has developed since then in response to a complex interplay of geological and hydrological factors (Figure 8). Based on evidence observed in the cave (described in more detail in Graf, in press), the speleogenetic history includes the following: (1) a significant initial episode of solutional activity at or near the water table; (2) lowering of the water table with ensuing passage enlargement due to ceiling breakdown and vadose (open channel flows and films above the water table) solution and erosion; (3) speleothem formation in the air-filled passages; (4) one or more backflooding events or water-table rises that cut distinctive corrosion bevels into speleothems and limestone bedrock (Carol Hill, personal commun.); (5) deposition of a sequence of clastic sediments, from laminated clays to granite cobbles up to 1 foot in diameter; (6) continued speleothem formation, including flowstone deposition over the clastic-sediment sequence; and (7) erosion of the clastic-



sediment sequence by energetic, in-cave stream flows.

The geology and speleogenesis of Kartchner Caverns are being defined in greater detail by several current studies. These include geophysical investigations using natural-potential, microgravity, and electromagnetic (EM) methods; mineralogical studies; uranium-series dating and oxygen-isotope analysis of key speleothems; paleomagnetic studies of clastic sediments; and detailed geologic mapping, both on the surface and underground. Radiocarbon dating of fossil guano and other suitable material will also be attempted. The cave is the summer migratory and maternity home for approximately 1,000 Cave bats (*Myotis velifer*), which are being studied as part of the concurrent biological investigations. Fossil guano deposits and bat bones have been discovered in areas of the cave that are now inaccessible to the bats.

Cave Meteorology

The cave microclimate and meteorology study will be critical in guiding the planning and development of Kartchner Caverns. Large parts of the cave are still "live." In the live areas, calcite is still being deposited and speleothems are forming (Figure 9). Changes in airflow, temperature, or humidity caused by improper development could quickly dry out the cave, halt speleothem growth, and diminish the cave's beauty.

To assess baseline conditions, 22 meteorological monitoring stations have been installed in the cave. At each station, electronic temperature sensors record maximum and minimum air and soil temperatures. Other parameters being measured include humidity, evaporation rates, airflow, barometric changes, air quality, and drip rates. The temperature recorders indicate that the coldest temperature in the cave is 65.4°F at Pirates' Den; the warmest temperature is 69.6°F at the Overlook in the Big Room. Temperatures remain virtually constant throughout the cave, except near the entrance, where seasonal fluctuations have been noted. The average evaporation rate for all stations within the cave (exclusive of the entrance area) is 0.10 inches per year, in marked contrast to a typical surface evaporation rate of about 70 inches per year. Humidities are correspondingly high, varying between 96.0 and 99.2 percent, except for reduced humidities in the constricted entrance passages, where some air interchange between the surface and the cave occurs (Dr. Todd Rasmussen, Univ. of Arizona, personal commun.).

Summary

In a few years, the wonders discovered by two cavers in 1974 and kept secret for so long will be open for all to view. The baseline information gained during the current geological, hydrological, meteorological, and biological studies will allow Arizona State Parks to develop Kartchner Caverns as a premier park for visitation and education. These studies will also ensure that the quiet beauty and nearly pristine condition of Kartchner Caverns will be preserved, to delight visitors for years to come.

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Charles Graf is a hydrologist at the Arizona Department of Environmental Quality in Phoenix, where he manages the Superfund Hydrology Unit. Off hours, he has volunteered time supporting the Kartchner Caverns project.

Mr. Graf wishes to acknowledge Robert H. Buecher and Randy Tufts, project manager and secretary, respectively, of Arizona Conservation Projects, Inc., for their assistance in preparing this article.

Water Conservation Is Topic of National Symposium

During the summer of 1988, the United States weathered a destructive drought that focused the public's attention on the greenhouse effect and the apparent inability of this Nation to meet the water demands of its citizens. Buying and selling water reserves in the West is now common. As the supply of potable water continues to evaporate because of increased demand and pollution, bargaining for water could also become common in the East.

To address these concerns, nearly 60 national organizations are coordinating what is considered to be the most important water-supply conference and exposition in U.S. history. Called CONSERV 90, it will convene in Phoenix August 12-15, 1990. The conference will include workshops, debates, field trips, and more than 100 talks. The most water-efficient equipment will be on display. CONSERV 90 is targeted for lawmakers, city managers, industrial engineers, environmentalists, and media personnel, as well as "water professionals." Some of the latter group compose a Speakers Bureau and are available to address water-resource problems and share vital information with organizations.

For more information, write to CONSERV 90, 6375 Riverside Dr., Dublin, OH 43017 or call (614) 761-1711.

Applied Geology Is Focus of Field Trip

Earth science teachers examine a gypsum quarry near Winkelman, Arizona. The teachers were participants in a field trip, "Applied Geology of the Basin and Range Province of Arizona," led by Thomas G. McGarvin and Larry D. Fellows of the Arizona Geological Survey. The day-long excursion included stops at a limestone quarry, cement plant, gypsum quarry, copper mine, and 10-mile-long earth fissure caused by land subsidence. The field trip was one of several offered during the National Science Teachers Association Regional Convention, held in Phoenix from November 30 to December 2, 1989.

Summary of Earthquake Activity in Arizona for 1989

NORTHERN ARIZONA

by David S. Brumbaugh, Director
Arizona Earthquake Information Center

The year 1989 was marked by a sharp increase in earthquake activity. This capped a trend during the last half of the decade towards larger and more frequent events (Figure 1). The number of earthquakes of local magnitude equal to or exceeding 2.0 ($M_L \geq 2.0$) increased nearly 200 percent over that in 1988. Nearly all of the events were concentrated in three areas in the northern part of the State: the Grand Canyon, the Mogollon Plateau, and the Arizona Strip (Figure 2).

The most active of these three areas was the Grand Canyon. A swarm of events was noted in the canyon area in early September 1988; three of these registered $M_L \geq 3.0$ (Bausch, 1989). Activity subsided until March 5, 1989, when the South Rim was rocked by two M_L 4.0 earthquakes, the largest to occur in Arizona since the M_L 5.0 Chino Valley earthquake of 1976. These two shocks caused only minor damage at Grand Canyon Village, but triggered several rock falls in the canyon and associated earthquake lights (methane gas, or fireballs, expelled near faults, usually during large strike-slip events that fracture the rocks). The maximum intensity of ground shaking reported was VI. During the next week, more than 100 aftershocks were recorded, 15 of which were $M_L \geq 2.0$. The rest of 1989 at the South Rim was quiet, except for three earthquakes of M_L 2.9, 2.8, and 2.2 in September, one of M_L 3.0 in November, and one of M_L 2.9 in December (Table 1).

Activity on the Mogollon Plateau southeast of Flagstaff was initiated by an M_L 3.4 earthquake at Chavez Mountain on April 18. Events continued through September 1989, at times in swarms. Two other earthquakes of $M_L \geq 3.0$ occurred on July 17 and September 6. The latter shock was part of a cluster of five events that day near Sunset Mountain.

Other than the M_L 4.0 events at the canyon, the largest earthquakes in northern Arizona in 1989 occurred in the Arizona Strip northwest of the Grand Canyon. These included one event at Colorado City on February 4 (M_L 3.2), two near Fredonia on September 19 (M_L 3.7) and 21 (M_L 3.3), and one on the Paria Plateau on December 31 (M_L 3.6).

Earthquake activity in Arizona during 1989 occurred in two areas that had previously been noted for their seismicity: the Grand Canyon and Arizona Strip. The extensive seismicity on the Mogollon Plateau, however, was surprising. Historically, this area has been almost completely aseismic; it will certainly bear watching in 1990. To aid observation, the Arizona Earthquake Information Center is installing a permanent seismograph station at Blue Ridge, near the center of the Mogollon Plateau.

SOUTHERN ARIZONA

by Terry C. Wallace
Department of Geosciences
University of Arizona

The University of Arizona operates a World Wide Standardized Seismic Network (WWSSN) station, TUC, in the Catalina Mountains. The station's instrumentation consists of six seismographs: three short-period components and three long-period components. The former are run at high magnification (100,000 X) and are extremely effective for monitoring seismic activity within 500 kilometers of Tucson. In cooperation with the Arizona Sonora Desert Museum, the University of Arizona attempts to identify and locate all earthquakes that affect southern Arizona (at latitudes lower than 34° N). TUC can locate earthquakes of $M_L \geq 2.5$ in Cochise, Graham, Greenlee, Pima, Pinal, and Santa Cruz Counties and events of $M_L > 3.5$ elsewhere in the State.

The background seismicity level for southern Arizona is quite low, especially compared to California. The two most seismically active regions in southern Arizona are the southeastern corner of the State, extending north from Douglas along the New Mexico border to the Clifton-Morenci area, and the southwestern corner south of Yuma along the Mexico-Arizona border. During a typical year in southeastern Arizona, a single earthquake with $M_L > 3.0$ will

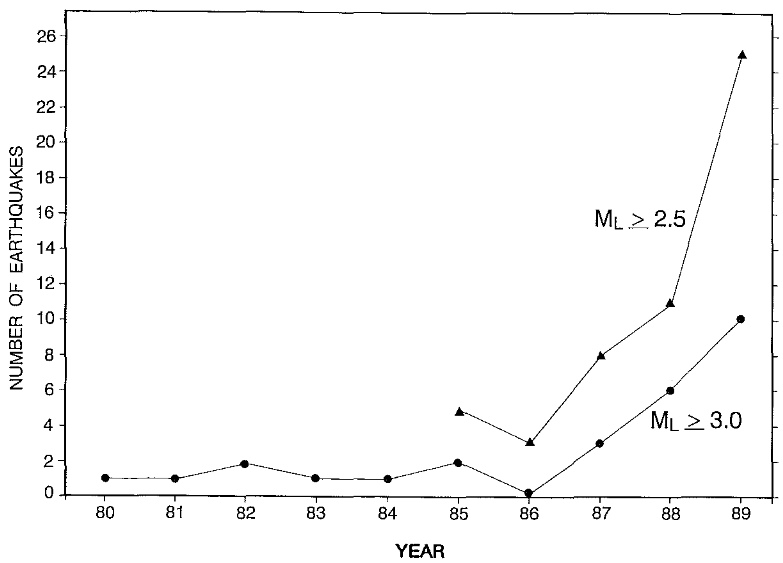

Figure 1 (above). Trend of seismic activity in northern Arizona for 1980-89. M_L = local magnitude.

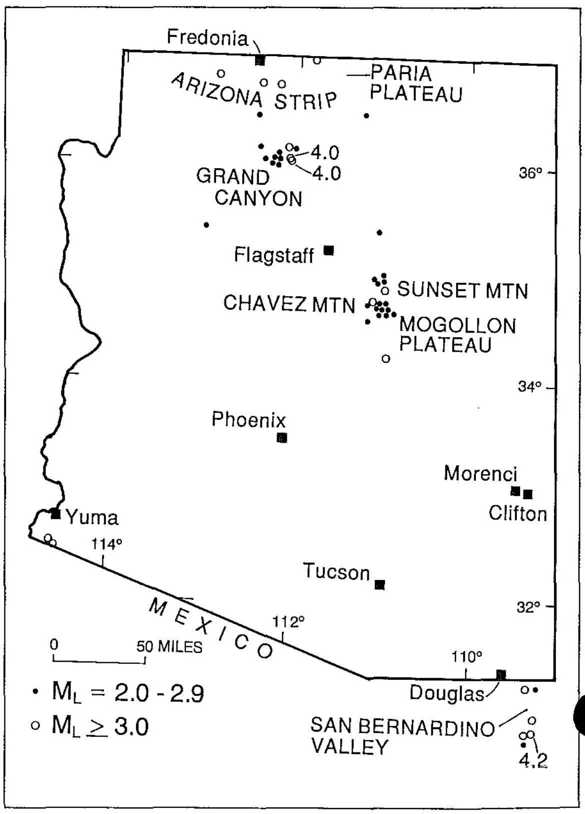

Figure 2 (right). Epicenters of earthquakes of $M_L \geq 2.0$ that occurred in Arizona during 1989. The three earthquakes of $M_L \geq 4.0$ are identified. See Table 1 for more precise magnitudes of other earthquakes.

occur. In contrast, during one year the Yuma area will be shaken by at least one event with $M_L > 4.5$. Most of the seismicity that affects the Yuma region is actually located in California or Mexico and is associated with the southern terminus of the San Andreas system. The seismicity in southeastern Arizona appears to be related to the range fronts of the north- to northwest-trending mountains. The most active regions have been southeast of Douglas in the San Bernardino Valley of Sonora and near Clifton-Morenci.

The earthquake activity in southern Arizona during 1989 was concentrated in the San Bernardino Valley (Figure 2; Table 1). The largest earthquake in this area in 25 years occurred on May 25 (M_L 4.2; the National Earthquake Information Center reported that m_b, or body-wave magnitude, was 4.6). This earthquake and its aftershocks on May 26 occurred near a major bend in the Pitaycachi fault (see Wallace and Pearthree, 1989). On June 9 and again on December 27, earthquakes occurred at the northern end of the valley near the Arizona-Sonora border. The seismic-energy release for this area during 1989 was extraordinarily high and represents a continuation of activity that began in March 1987 near the fault. This spring, the University of Arizona will install several temporary seismic stations in the southeastern corner of the State to monitor the valley in detail.

Although the Yuma area was shaken by several earthquakes in California and Mexico during 1989, only two were located within the boundaries of Arizona. These events occurred in February in the southwesternmost tip of the State. Both events registered an M_L of 3.1, but no one reportedly felt the tremors.

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Table 1. Arizona earthquakes ($M_L \geq 2.0$) detected in 1989 by the AEIC network and TUC station.

Date	Latitude[1] (°N)	Longitude[1] (°W)	Depth[2] (km)	Origin Time (UTC)[3]	M_L[4]	Epicenter
2-4	36.80	112.92	5	12:26:58	3.2	Colorado City
2-5	32.490	114.630	2	21:51:12.6	3.2	southwest of Yuma
2-5	32.400	114.610	6	22:05:15.9	3.2	southwest of Yuma
2-16	35.41	113.02	8.9	19:37:00	2.4	Aubrey Valley
3-5	36.02	112.10	10	00:40:32	4.0	Grand Canyon
3-5	95 km from FLAG		--	00:45:??	2.2	Grand Canyon
3-5	36.03	112.07	10	09:17:57	4.0	Grand Canyon
3-5	36.09	112.13	5F	09:35:59	2.1	Grand Cyn. aftershock
3-5	36.04	112.16	5F	14:40:42	2.5	Grand Cyn. aftershock
3-5	36.09	112.23	3F	17:22:10	2.0	Grand Cyn. aftershock
3-5	36.07	112.24	5F	20:51:10	2.2	Grand Cyn. aftershock
3-6	36.04	112.21	13.7	13:09:22	2.1	Grand Cyn. aftershock
3-7	36.03	112.21	13.3	01:59:08	2.2	Grand Cyn. aftershock
3-7	36.03	112.26	14.3	04:08:39	2.3	Grand Cyn. aftershock
3-7	36.04	112.16	7.4	08:24:40	2.5	Grand Cyn. aftershock
3-7	35.98	112.23	13.8	14:14:20	2.4	Grand Cyn. aftershock
3-8	36.15	112.42	16.0	02:51:52	2.3	Grand Cyn. aftershock
3-9	36.00	112.28	11.9	06:44:50	2.1	Grand Cyn. aftershock
3-9	36.05	112.22	12.5	12:16:27	2.7	Grand Cyn. aftershock
3-10	36.06	112.23	14	11:00:44	2.9	Grand Cyn. aftershock
3-10	36.01	112.23	11	15:31:33	2.5	Grand Cyn. aftershock
4-18	34.76	111.10	15.6	10:45:52	3.4	Chavez Mountain
4-26	34.58	111.18	22	23:28:50	2.5	Mogollon Plateau
4-30	34.75	111.05	14.6	16:37:21	2.6	Mogollon Plateau
5-4	34.72	110.95	10	22:46:41	2.4	Mogollon Plateau
5-4	34.70	110.92	20	22:58:07	2.7	Mogollon Plateau
5-8	34.64	111.04	2	03:12:08	2.7	Mogollon Plateau
5-9	34.68	111.08	10	07:55:54	2.0	Mogollon Plateau
5-13	36.50	111.24	9	01:06:47	2.6	Kaibito Plateau
5-14	65 km from FLAG		--	06:10:4?	2.0	Chavez Mountain?
5-15	35.37	111.04	10	06:03:37	2.2	Mogollon Plateau
5-18	34.70	111.03	10F	02:35:39	2.5	Mogollon Plateau
5-20	34.68	111.00	9	00:46:42	2.0	Mogollon Plateau
5-20	34.68	110.95	5	01:31:52	2.2	Mogollon Plateau
5-22	34.78	111.02	5.7	14:25:53	2.0	Mogollon Plateau
5-25	30.841	109.332	9	07:43:18.5	4.2	near Colonia Morelos
5-26	30.820	109.382	5	09:08:10.7	3.7	near Colonia Morelos
5-26	30.742	109.401	--	11:52:11.2	2.5	near Colonia Morelos
6-9	31.252	109.271	--	17:03:20.7	2.8	Arizona-Sonora border
6-29	36.44	112.48	10.0	03:09:18	2.4	Steamboat Mountain
7-10	34.94	111.09	18	00:31:53	2.4	Mogollon Plateau
7-17	34.25	110.92	10	20:10:24	3.0	Mogollon Plateau
9-6	34.91	111.17	29	12:30:13	2.0	Sunset Mtn. foreshock
9-6	34.99	111.00	3	12:33:29	2.3	Sunset Mtn. foreshock
9-6	34.87	110.99	20	12:36:55	3.2	Sunset Mtn. main shock
9-6	34.94	111.00	38	14:18:39	2.1	Sunset Mtn. aftershock
9-6	34.98	111.01	2	17:23:21	2.6	Sunset Mtn. aftershock
9-6	36.03	112.37	10F	18:26:52	2.9	Grand Canyon
9-12	36.02	112.29	2	06:46:10	2.2	Grand Canyon
9-15	36.02	112.21	4.5	12:30:57	2.8	Grand Canyon
9-19	36.74	112.23	10F	09:46:01	3.7	Fredonia
9-21	36.77	112.44	5.5	15:38:46	3.3	Fredonia
11-28	36.10	112.20	10F	18:37:32	3.0	Grand Canyon
12-7	36.13	112.03	15F	23:14:04	2.9	Grand Canyon
12-27	31.216	109.381	--	13:18:45.4	3.1	Arizona-Sonora border
12-27	30.967	109.291	7	14:00:16.9	3.1	San Bernardino Valley
12-31	36.98	111.83	10F	09:20:49	3.6	Paria Plateau

1 FLAG = Seismic research station at Northern Arizona University, Flagstaff
2 F = Fixed
3 UTC = Universal Time Coordinated
4 M_L = Local magnitude

Newsletter Links Teachers With Scientists

Earth science teachers in grades K-12 have a new link with scientists who research the topics they teach. The National Center for Earth Science Education of the American Geological Institute (AGI) publishes a quarterly newsletter that describes projects, conferences, seminars, and publications devoted to enhancing the quality of earth science education. Subscriptions to *Earth Science Education Connection* are free from AGI, 4220 King St., Alexandria, VA 22302-1507; tel: (703) 379-2480.

1989 Earthquake Tally

Although the magnitude 7.1 Loma Prieta earthquake that struck the Santa Cruz area of California on October 17 made Americans especially earthquake sensitive, the world actually had fewer significant earthquakes during 1989 than the average for the past two decades. The 55 significant earthquakes during 1989 were 6 fewer than the total for 1988. The U.S. Geological Survey defines a significant earthquake as one that registers a magnitude of at least 6.5 or one of lesser magnitude that causes casualties or considerable damage.

In addition, the number (526) of persons who died in 1989 as a result of earthquakes was significantly lower than the number (28,000) who died in 1988 and well below the average of 10,000 deaths per year.

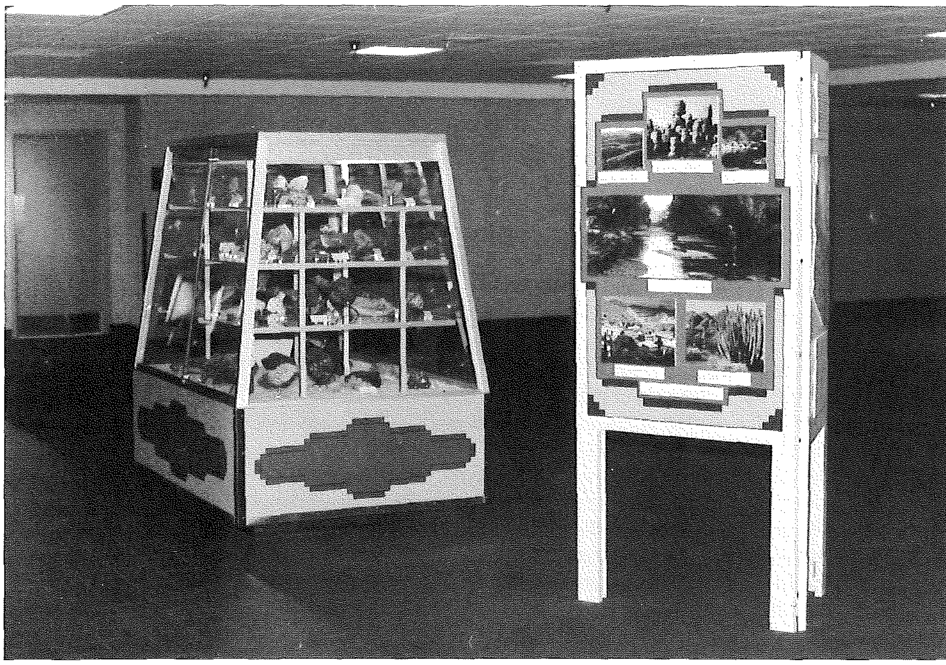
CLARIFICATION

In the article "Patterns of Earth-Fissure Development: Examples From Picacho Basin, Pinal County, Arizona" (*Arizona Geology*, v. 19, no. 3, p. 4-5), the author referred to a fissure that was first reported in 1929 and is now at least 15.8 kilometers (9.8 miles) long. The fissure reported in 1929 was in approximately the same location, but may not be the same fissure, as the one that is now more than 15 kilometers long.

Arizona River Guide

Arizonans love water with a passion that is honed by the stark dryness of their desert surroundings. A new book published by Arizona State Parks directs water worshippers to that liquid Mecca. *Arizona Rivers and Streams Guide* describes 74 of the State's most outstanding waterways. It also provides information on fishing, hiking, camping, canoeing, kayaking, rafting, tubing, and wildlife watching. The guide includes a map of each area, gives directions on how to get there, describes the area's unique features, and lists regulations and required permits. Copies are available for $7.95, plus $1.00 for shipping and handling, from Arizona State Parks, 800 W. Washington, Suite 415, Phoenix, AZ 85007. Many bookstores and outdoor-equipment stores also sell the book.

Geologic Display Greets Visitors to the Southwest



Visitors to the Tucson International Airport have an opportunity to see rocks and minerals common to Arizona and photographs of geologic features in the southern part of the State. The Arizona Geological Survey (AZGS) has constructed a display that includes specimens donated by the University of Arizona Mineral Museum, photographs taken by Peter L. Kresan, and a geologic map of Arizona published by the AZGS. The display, shown above, was designed by AZGS graphic artist, Peter F. Corrao, in cooperation with Jan Crebbs, Communications Coordinator, Airport Information Department. It is centrally located on the second floor of the terminal.

Educational Poster Available

"From Mountains to Metal: The Story of Rocks, Minerals, and the Mining Industry," is the title of a new educational poster developed by the National Energy Foundation in cooperation with the U.S. Bureau of Mines. The front side of the poster, which is printed in color, shows men and women working at various jobs in the mining industry, from exploration and ore processing to transportation and land reclamation. The text and drawings are appropriate for children in 5th grade through junior high school. The reverse side of the poster gives more detailed information on rocks and minerals, such as crystal structures and commercial uses, and was designed for children in high school or even college. The poster was distributed to teachers nationwide in the November/December 1989 issue of *Science and Children*. Copies are still available from the National Energy Foundation, 5160 Wiley Post Way, Suite 200, Salt Lake City, UT 84116; tel: (801) 539-1406. Single copies are $3.00 (including shipping and handling); inquire about bulk orders.

Arizona's Industrial Minerals: Workshop Proceedings

The value of nonfuel-mineral production in the United States in 1989 is estimated at $31.8 billion, of which $20.2 billion is from industrial minerals and $11.6 billion is from metals. Industrial rocks and minerals are an often overlooked, but nevertheless economically important, resource in Arizona. The State is experiencing increasing pressure to expand its economy to accommodate an explosive growth in population, which, in turn, accelerates the use of industrial rocks and minerals. A workshop to improve public and private understanding of this resource was held May 17-18, 1988 in Tempe, Ariz. and was jointly sponsored by the U.S. Geological Survey (USGS) and Arizona Geological Survey. Information from that workshop is summarized in USGS Bulletin 1905, *Arizona's Industrial Rock and Mineral Resources – Workshop Proceedings.* Recommendations concerning data acquisition and management, computer technology, and geotechnical research, among others, outline how resource data are used and what information is still needed. Copies of Bulletin 1905 are available for $5.00 each from the Books and Open-File Reports Section, U.S. Geological Survey, Federal Center, Box 25425, Denver, CO 80225.

USGS Computer Programs

During the past 25 years, the U.S. Geological Survey (USGS) has released nearly 500 publications that contain computer programs. An index of these has been released as USGS Open-File Report 89-681, which lists authors, prices, and subject areas as well as titles. Most of the reports in the index include computer programs only as hard-copy source code, although some of the more recent publications also contain floppy disks.

USGS computer programs are written for applications such as resource appraisals, earthquake studies, water-quality analyses, seismic exploration, image processing, and mapping. Popular programs include GSMAP and GSDRAW for compiling and drafting geologic maps and illustrations, muPETROL for classifying sedimentary basins, SEISRISK III for estimating seismic hazards, and MODPATH for determining ground-water flow.

A copy of Open-File Report 89-681, Computer Programs Released as U.S. Geological Survey Publications Through August 1989, may be purchased for $11.00 (paper) or $4.00 (microfiche) from the Books and Open-File Reports Section, U.S. Geological Survey, Federal Center, Box 25425, Denver, CO 80225.

New AZGS Publications

The following publications may be purchased from the Arizona Geological Survey, 845 N. Park Ave., #100, Tucson, AZ 85719. Orders are shipped by UPS; a street address is required for delivery. All orders must be prepaid by check or money order payable in U.S. dollars to the Arizona Geological Survey. Add shipping and handling charges, listed below, to your total order:

\$1.01 - 5.00, add 1.75	40.01 - 50.00, add 7.75
5.01 - 10.00, add 2.25	50.01-100.00, add 10.00
10.01 - 20.00, add 4.25	Over 100.00, add 10%
20.01 - 30.00, add 5.50	Other countries, request price quotation.
30.01 - 40.00, add 6.25	

Welty, J.W., DeWitt, Ed, and Schnabel, Lorraine, 1989, Bibliography for metallic mineral districts in Gila, Maricopa, Pinal, and Yavapai Counties, Arizona: Circular 27, 81 p. \$11.00

This circular is the fourth in a series of county-by-county bibliographies for metallic mineral districts in Arizona. In a mineral-district classification, known metallic mineral deposits are grouped according to geologic and metallogenic criteria rather than the geographic associations used in the traditional mining-district approach. Nearly 1,600 citations are included in this report.

Welty, J.W., and Chenoweth, W.L., 1989, Bibliography for metallic mineral districts in Apache, Coconino, and Navajo Counties, Arizona: Circular 28, 47 p. \$9.00

This is the fifth and last circular in the bibliographic series for metallic mineral districts in Arizona. In addition to sections for each mineral district, this bibliography devotes a special section to solution-collapse breccia-pipe uranium deposits. The report contains nearly 1,000 citations.

Gehrels, G.E., and Spencer, J.E., eds., 1990, Geologic excursions through the Sonoran Desert region, Arizona and Sonora: Special Paper 7, 202 p. \$18.00

The 86th annual meeting of the Cordilleran Section of the Geological Society of America was held in Tucson, Arizona in March 1990. The occasion provided an opportunity for geologists studying central and southern Arizona and Sonora, Mexico to lead field trips to their study areas. Field guides for 16 of the 18 field trips run in association with this meeting are included in this special paper. This publication offers a guide to outstanding and generally accessible geologic features in the Southwest and explanations of their geologic significance.

Grubensky, M.J., 1989, Geologic map of the Vulture Mountains: Map 27, scale 1:24,000, 3 sheets. \$15.00

This map provides complete and thorough coverage of the geology and mineral deposits of the Vulture Mountains, including some areas covered in previous maps (AZGS Open-File Reports 87-10, 88-9, and 88-10). The three large sheets, which show the lithology, stratigraphy, structural geology, and mineral deposits of this area, are printed in black and white on durable high-quality paper.

Welty, J.W., 1989, Additions to bibliographies for metallic mineral districts in Arizona: Open-File Report 89-9, 26 p. \$4.00

This report is an update to published county-by-county bibliographies for metallic mineral districts in Arizona (AZGS Circulars 24, 25, 26, 27, and 28). More than 175 new citations are listed.

Demsey, K.A., and Pearthree, P.A., 1990, Late Quaternary surface-rupture history of the Sand Tank fault and associated seismic hazard for the proposed Superconducting Super Collider site, Maricopa County, Arizona: Open-File Report 90-1, 43 p. \$6.75

The Sand Tank fault, 10 kilometers southwest of the proposed Superconducting Super Collider site in Maricopa County, is characterized by a 3.5-kilometer-long northeast-trending scarp with a maximum displacement of 2 meters. Evidence suggests that the scarp was formed during a single late Quaternary (8,000 to 20,000 years ago) rupture event, which generated a magnitude 6.2 to 6.6 earthquake. This seismotectonic geomorphic study integrates data from soil-stratigraphic records, local geomorphic surface relationships, fault-scarp morphology, aerial-photo interpretation, and empirical seismicity--surface-rupture relationships. The results of the study indicate that the potential seismic hazard posed by the Sand Tank fault is very low.

Jackson, Garrett, 1990, Surficial geologic maps of the Picacho basin: Open-File Report 90-2, 9 p., scale 1:24,000, 5 sheets. \$9.00

The Picacho basin is a large and complex graben surrounded by horsts and half-horsts, which are now the Picacho, Casa Grande, Silverbell, and Sacaton Mountains. The basin formed mainly in response to late Miocene extension. Internal drainage probably persisted until about 3 million years ago. Several thousand meters of sediments now fill the basin. Surficial geology is dominated by three basic landform types: eolian landforms, basin terraces, and alluvial fans.

This open-file report details the surficial geology of the Picacho basin. Through mapping and interpretation of Quaternary landforms, including relative age assessments, the author has evaluated geologic hazards in the basin, including flooding, debris flows, earth fissures, and soil-related problems.

Ciesiel, Robert, and Gray, I.B., 1989, Geologic map of the underground workings of the Harve Black No. 2 mine, Navajo County, Arizona, with a text by W.L. Chenoweth: Contributed Report CR-89-E, 7 p. \$4.00

During the mid-1950's, the two primary authors, geologists with the U.S. Atomic Energy Commission, mapped the geology of several underground uranium mines in the Monument Valley area of Arizona and Utah. The Harve Black No. 2 ore deposit is contained in the Shinarump Member of the Chinle Formation. The mine is on the rim of a small mesa 2.5 miles southwest of Goulding Trading Post and Lodge on the Navajo Indian Reservation. In addition to the map, this report includes information on the geologic setting and production history of the mine.

Chenoweth, W.L., 1989, Leasing and mining of carnotite deposits in the 1920's, Carrizo Mountains, Apache County, Arizona and San Juan County, New Mexico: Contributed Report CR-89-F, 48 p. \$7.00

Many of the carnotite deposits in southwestern Colorado and adjacent parts of Arizona, New Mexico, and Utah are contained in the Upper Jurassic Salt Wash Member of the Morrison Formation. The Salt Wash Member is exposed along the perimeter of the Carrizo Mountains and in the northwestern corner of San Juan County, New Mexico. The bright-yellow mineral carnotite, a potassium-uranium vanadate, gave the deposits their name. During the early 1920's, the ores were mined for their vanadium content. This report summarizes the geologic setting, mining, and leasing of these deposits.

Weeks Appointed to State Board of Technical Registration

Ralph E. Weeks, Director of Environmental Services at Sergent, Hauskins & Beckwith, has been appointed by Governor Rose Mofford to serve a 3-year term on the State Board of Technical Registration. Mr. Weeks has a B.S. degree in geology from Northern Arizona University, is a registered geologist, and is a certified member of the American Institute of Professional Geologists. He also serves on the advisory board of the Arizona Geological Survey. The State Board of Technical Registration consists of nine members: three engineers, two architects, one landscape architect, one geologist or assayer, one land surveyor, and one representative from the general public.

Subject Index to *Fieldnotes* and *Arizona Geology*, 1971-89

compiled by Nancy Schmidt
Arizona Geological Survey

Fieldnotes, the newsletter of the Arizona Geological Survey (AZGS), has been published quarterly since the spring of 1971. The name was changed to *Arizona Geology* in the fall of 1988, starting with vol. 18, no. 3. This index includes issues that have been published from 1971 through 1989 and references articles by volume-number, page; for example, 14-3, 5 represents vol. 14, no. 3, p. 5. Three issues were combined issues: 6-3/4, 7-3/4, and 8-1/2.

Two agencies listed below have changed names since 1971:

(1) In 1977, the Arizona Bureau of Mines became the Arizona Bureau of Geology and Mineral Technology (ABGMT); in 1988, ABGMT became the Arizona Geological Survey (AZGS). Articles published under all three names are indexed under "Arizona Geological Survey."

(2) In 1984, the Arizona Department of Mineral Resources (DMR) became the Arizona Department of Mines and Mineral Resources (DMMR). Articles published under both names are indexed under "Arizona Department of Mines and Mineral Resources."

Most of these back issues are still in print and may be obtained by sending a shipping and handling fee to the AZGS. To obtain information on the availability and cost of back issues, contact the AZGS at 845 N. Park Ave., #100, Tucson, AZ 85719; tel: 602-882-4795.

Arizona Geology

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State of Arizona: Governor Rose Mofford

Arizona Geological Survey

Director & State Geologist: Larry D. Fellows
Editor: Evelyn M. VandenDolder
Editorial Assistant: Nancy Schmidt
Illustrators: Peter F. Corrao, Sherry F. Garner

U.S. Bureau of Mines Presents Academic Awards

The U.S. Bureau of Mines (BOM) announced the first award winners in a new Academic Outreach Program that promotes the study of economic and policy issues affecting the mineral industry. The winner of the Distinguished Young Scholar Award is Dr. Mark C. Roberts of Michigan Technological University, who specializes in the economics of advanced materials, such as plastics and high-tech alloys, and their impact on metal markets. Graduate Fellowship Awards were given to graduate students John H. Hill of the Colorado School of Mines, who will study the economic structure of the dimension stone industry, and Ralph R. Metcalf of the University of Illinois, who will examine the effects of alternative clean-coal technologies on the consumption of different types of coal. To meet its goal of ensuring adequate U.S. supplies of nonfuel minerals, the BOM works with colleges and universities to develop young talent in academic areas.

Careers in the Geosciences

A colorful new brochure summarizes for high-school students what geoscientists do and where they work. *Careers in the Geosciences* shows geoscientists collecting samples from streams and volcanoes, investigating caves and glaciers, interpreting maps, and using computer models. The brochure includes brief descriptions of work in 21 specialized fields, job and salary outlooks, and sources of information. It also outlines high-school prerequisites and undergraduate courses for a geology major. It was produced by the American Geological Institute (AGI), American Association of Petroleum Geologists, and Geological Society of America. Single copies are free; bulk orders cost $10 per 25 copies, plus shipping and handling fees. Contact the National Center for Earth Science Education, AGI, 4220 King St., Alexandria, VA 22302; tel: (800) 336-4764 or (703) 379-2480.

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